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Disequilibrium Adjustment and Economic Outcomes

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Abstract

A central organizing principle in contemporary economic theory is the notion of *equilibrium*: all individuals make plans that are *optimal*, given beliefs that are *mutually consistent*. The equilibrium method is effective in generating sharp predictions, but it sidesteps important questions about how equilibrium can be attained, optimality assessed, and available alternatives enumerated. This chapter describes an alternative approach in which the process of adjustment is a central theme. Individuals adapt to changes in their environment by making incremental changes in their behavior. These changes alter the environment faced by others, which leads to further dynamic adjustments. Trajectories may eventually converge to an equilibrium, but this is not inevitable. Even when convergence does occur, it may be to one of several conceivable equilibria, in which case the dynamics operate as an equilibrium selection device. These ideas are explored primarily through the example of homophily in social interactions, with other potential applications also briefly considered.

Introduction

A central organizing principle in contemporary economic theory is the notion of equilibrium. While there are many variations in its definition, equilibrium typically requires that all individuals make plans that are optimal given their beliefs, and that these beliefs are mutually consistent. Under these conditions all plans can be simultaneously executed, without any need or desire for adjustment as time unfolds, except possibly in response to exogenous shocks. Equilibrium does not require that plans be simple, only that they be compatible, and equilibrium trajectories can entail complex movements in economic magnitudes over time.

The methodology is extremely effective in narrowing the set of outcomes that can arise in an economic model. However, it sidesteps important questions about how equilibrium paths can be reached from an initial state of

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disequilibrium, and how individuals can reliably assess the optimality of their choices, or even fully catalog the set of alternatives available to them and others.

In this chapter we describe an alternative methodological approach in which the process of adjustment is itself a central theme, and individuals adapt to changes in their environment by making incremental improvements in their behavior. These changes alter the environment faced by others, which leads to further dynamic adjustments. The possibility remains that trajectories converge eventually to an equilibrium, but this is not inevitable by any means. Even when convergence to equilibrium does occur, it could be to one of several conceivable equilibria, in which case the adjustment dynamics operate as an equilibrium selection device.

We illustrate these ideas by focusing primarily on a single application: homophily in social interactions. In making decisions about patterns of association, the set of strategies available to individuals can be so large as to make continuous optimizing behavior implausible. Instead, one can model behavior based on simple payoff-improving adjustments or *disequilibrium dynamics*. This can be done with preferences held fixed or can involve endogenous changes in preferences based on evolutionary considerations. We argue that the paradigm of complexity, evolution, and disequilibrium adjustment provides a promising alternative to the prevailing equilibrium methodology in this application, and consider other potential applications in a concluding section.

Homophily

Homophily—the tendency of individuals to interact with others who share certain categorical characteristics—has been recognized and examined across the social sciences.[1] It is exhibited in the most intimate of relationships, such as marriage, as well as the most casual of interactions. It occurs on multiple dimensions, including characteristics that are largely endowed (e.g., ethnicity, gender, age) as well as those that are attained (e.g., education, occupational status). Religion and political preference, which are sometimes endowed and sometimes chosen, are a common basis for selective interaction.

Some degree of homophily can be accounted for by structural constraints on interaction. For instance, an individual who belongs to a demographic group that constitutes an overwhelming majority of the population is likely to have limited opportunities for interacting with members of minority groups. Selective interaction due to structural constraints is sometimes referred to as *induced homophily*, while *choice homophily* arises when individuals actively seek out others similar to themselves. The evidence is overwhelming that

1 Lazarsfeld and Merton (1954) are generally credited with coining the term *homophily* and associating it with the proverb “birds of a feather flock together” (McPherson et al. 2001).

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observed homophily vastly exceeds levels predicted by structural constraints alone, although choice and induced homophily can interact dynamically in complex ways (Kossinets and Watts 2009).

To the extent that homophily arises from human agency, it results from decentralized uncoordinated decisions made by individuals with limited and local knowledge of their environment. Each decision to form or break a relationship has an impact on the well-being and constraints faced by others, and can give rise to a cascading sequence of choices that is difficult to predict in advance. Even holding constant the preferences of individuals, the resulting dynamics of interaction can be highly complex. Furthermore, the preferences themselves need to be taken into account. A complex systems perspective can shed light on the manner in which homophily arises as an emergent property of a system with many interacting parts. In addition, an evolutionary perspective can illuminate the underlying preferences that form the basis for interaction decisions.

Evidence

In a survey of the sociological literature on the subject, McPherson et al. (2001:415) conclude that homophily "in race and ethnicity creates the strongest divides in our personal environments, with age, religion, education, occupation, and gender following in roughly that order."

To illustrate the extraordinary salience of racial markers in American life, consider the two maps of Manhattan shown in Figure 2.1, taken from Sethi and Somanathan (2009). The map on the left describes the racial composition of each census tract in the city, based on data from the 2000 census. Specifically, it depicts the number of black households as a proportion of households identified as either black or white in the tract, with all other groups omitted. The level of segregation is striking, yet consistent with earlier findings for many of the large metropolitan areas in the Northeast and Midwest of the United States (Massey and Denton 1993; Farley and Frey 1994).

Furthermore, observed segregation levels cannot simply be attributed to differences in income across groups, coupled with segregation by income. This can be seen by looking at the map on the right of Figure 2.1, which shows the degree of segregation that would arise if households sorted themselves based on income alone. The figure depicts a hypothetical Manhattan in which each neighborhood has the same number of households in each income category as the actual city, but the racial composition within each income category of each neighborhood equals the citywide racial composition in that category. If segregation by race were simply a side effect of sorting on the basis of household income, we would observe substantially lower levels of segregation.

Even environments that appear to be integrated at a high level of aggregation may be characterized by substantial segregation at the level of individual interactions. An example of this is visible in Figure 2.2, based on an analysis

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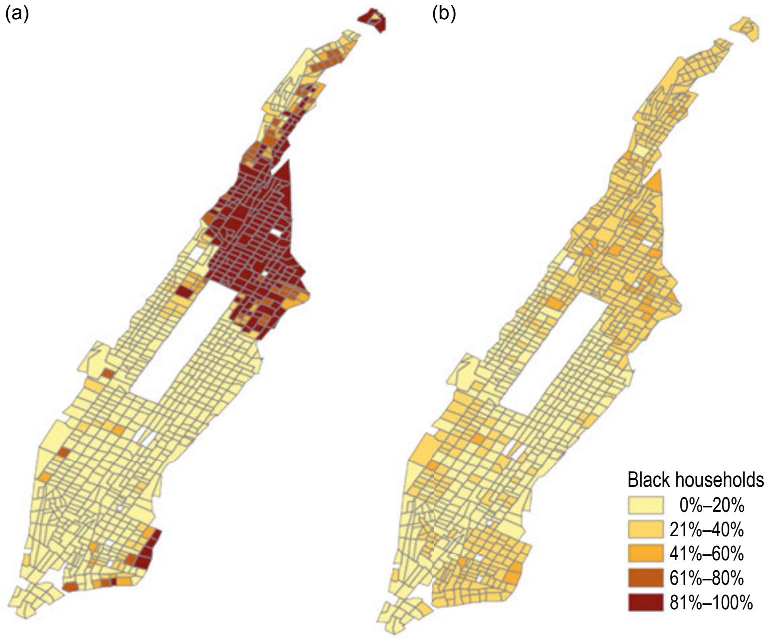

Figure 2.1 (a) Racial composition of each census tract in Manhattan, based on data from the 2000 census. (b) Hypothetical distribution based on the same population and income distribution in each tract, but minus the racial segregation within each income category (Sethi and Somanathan 2009; used with permission from Springer).

by Moody (2001). Figure 2.2 depicts self-reported friendships in a school, in the form of a directed graph: each node corresponds to an individual and each arrow a direction, indication that the source has named the target as a friend. The visual depiction of the network relies on a *spring algorithm*, which places nodes in close spatial proximity if there are a large number of links connecting them. As a result, the clusters observed in the figure may be interpreted as social clusters or communities of friends.

There are four such clusters in the graph: two are predominantly white and two predominantly black. The reason for four rather than two clusters is that the population of respondents is made up of students from different grade levels. While segregation by grade is to be expected, and corresponds in large measure to induced homophily, the figure reveals that segregation by race is just as extreme as segregation by age—in a school that would appear to be highly integrated at the aggregate level, with both black and white students well represented.

Figure 2.2 reveals that the level of aggregation at which homophily is measured matters a great deal: schools or neighborhoods that appear to be integrated may, in fact, be quite segregated on a finer level of individual interaction. For instance, cities in the southern United States have historically had lower

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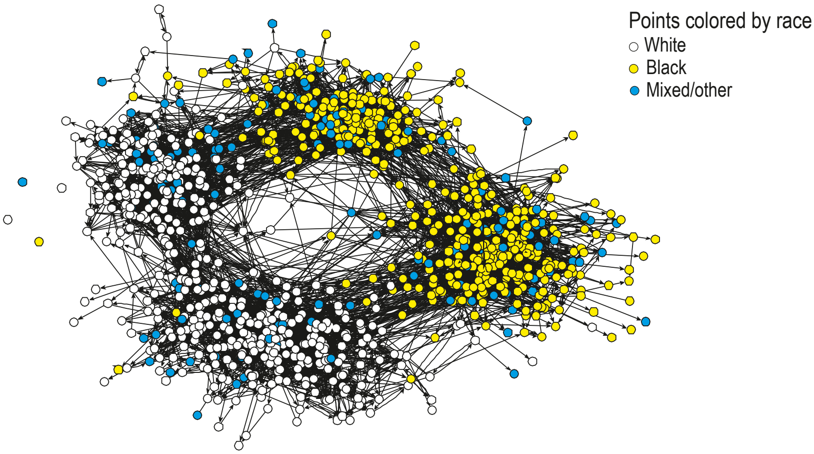

Figure 2.2 Segregation in adolescent friendship networks. Data from Moody (2001); figure provided by the author and used with permission.

levels of measured segregation based on neighborhood composition, when compared with those in the Northeast and Midwest. However, when segregation is measured based on the identity of next-door neighbors, southern cities are found to be considerably more segregated (Logan and Parman 2015). The geography of these cities, with their avenues and alleys, allows for segregated streets within seemingly integrated neighborhoods.

Theory

Empirically observed patterns of interaction tell us very little about the mechanisms that gave rise to them. In principle, one could attempt to build models based on the equilibrium method that are consistent with the data. For networks, if individuals can form links to others unilaterally, an equilibrium would simply be a pattern of connection such that no individual wants to form or sever a link (e.g., Bala and Goyal 2000). If mutual consent were required to form links, one could define equilibrium to be a state in which no individual wants unilaterally to sever a link and no unlinked pair wants to form one (e.g., Jackson and Wolinsky 1996). Once individual payoffs have been specified as a function of the network structure, such concepts could be used to identify equilibrium structures.

The equilibrium approach has proved fruitful in a number of applications (for comprehensive surveys, see Goyal 2009; Jackson 2010), but it also has limitations. The adjustment process through which an equilibrium is reached is typically left unspecified, and convergence to an equilibrium state is assumed rather than demonstrated. Also, there can exist a large multiplicity of equilibria

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with very different qualitative properties for any given specification for individual preferences. Even if convergence to *some* equilibrium can be assumed, there may be considerable indeterminacy with respect to the levels of segregation that can arise.

An alternative approach, which takes the dynamics of adjustment itself as a starting point, was introduced by Thomas Schelling (1971). He demonstrated that extreme levels of segregation could arise through a sequence of decentralized, uncoordinated location choices even if all individuals had tolerant preferences over neighborhood composition. The method he used to do so demonstrated the value of what have come to be called *agent-based computational models*, in which aggregate patterns in a system arise as emergent properties that depend critically on the structure of interaction, and cannot simply be deduced from the behavioral rules adopted by individuals.

Schelling's model of "self-forming neighborhoods" is deceptively simple.[2] A set of individuals occupies locations on a two-dimensional grid, and each individual belongs to one of two identity groups. Preferences over locations depend only on the composition of an individual's neighborhood, defined as the eight cells immediately adjacent to that occupied by the individual. If the proportion of neighbors belonging to one's own group strictly exceeds one-third, the individual in question is satisfied; if not, he/she will attempt to move to a location in which this criterion is met.

It is easily seen that these preferences are tolerant enough to allow for perfect integration. For instance, if the two groups were of equal size in the population, an assignment of individuals to locations could be constructed such that each neighborhood has the same share of the two groups. Schelling (1978) demonstrated, however, that such integrated allocations are virtually impossible to reach if the system is perturbed (so that a few individuals are dissatisfied) and then allowed to adjust through a sequence of movements made by those seeking satisfactory locations. In fact, patterns emerging from such dynamics typically exhibit very high degrees of segregation.[3]

The allocations that emerge as limit points of the dynamics in Schelling's model are indeed equilibria, in the sense that no individual wants to change location given the location choices of all others in the population. Nonetheless, there are also highly integrated allocations that are equilibria in the model. In fact, sufficiently small perturbations from an initial integrated equilibrium state are self-correcting in the sense that integration is restored under the dynamics. What Schelling demonstrated is that starting from essentially arbitrary

[2] The discussion here is based on the specification in Schelling (1978). A good account of subsequent variants of the model is given in Pancs and Vriend (2007).

[3] Schelling's interpretation of this finding is as follows: "People who have to choose between polarized extremes...will often choose in a way that reinforces the polarization. Doing so is no evidence that they prefer segregation, only that, if segregation exists and they have to choose between exclusive association, people elect like rather than unlike environments" (Schelling 1978:146).

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allocations, a dynamic path resulting in convergence to an integrated state is extremely unlikely to arise. Segregated states are reached from a large set of initial allocations with varying levels of integration, whereas integrated states can only be reached from a small set of initial states, all of which are already highly integrated. This insight is difficult to gain using equilibrium reasoning alone.

A number of important features are missing from the Schelling model: there is no heterogeneity across individuals or groups in characteristics (e.g., income, wealth, education), no discrimination in mortgage lending, no racial steering by real estate agents, no markets for locations and hence no capacity for one person to outbid another, and a relatively crude specification of preferences. Nevertheless, the key insight has been reproduced in a number of more orthodox models and has found empirical validation in many studies (see especially Cutler et al. 1999; Card et al. 2008).

Extensions

Variants of the Schelling model exist in which convergence itself cannot be taken for granted. Pancs and Vriend (2007), for example, consider alternative specifications for preferences over neighborhood racial composition. Schelling's specification involves a discontinuous upward jump in well-being when a threshold share of own-group neighbors is reached. In one of the alternative specifications, people exhibit a preference for heterophily, with peak utility arising when neighborhoods are evenly mixed. This induces exit from homogeneous neighborhoods, as individuals seek out locations in which both groups are well represented.

One might expect convergence to integrated equilibria under these assumptions, but what one sees instead are high levels of segregation with continuously shifting boundaries. Here one finds order at the aggregate level while individual behavior is in constant flux. People move toward the boundaries between segregated clusters, thus shifting these boundaries, but without convergence to integrated allocations. This kind of dynamic behavior is even more difficult to capture using equilibrium methods.

Pancs and Vriend (2007) maintained Schelling's agent-based method, while modifying his assumptions regarding individual preferences, to generate complex dynamics that can fail to converge to any equilibrium state. We next describe work that takes Schelling's model in a different direction, drawing on an analogy with the physical sciences.

Although early economists, such as Walras and Pareto, attempted to use methods from physics to understand economic phenomena, there has been a reluctance to do so in modern economics. This is to some degree understandable. As Keynes wrote in a 1938 letter to Harrod, economics is a moral science that deals with introspection and values, so that one must be "on guard against treating the material as constant and homogeneous in the same way that the material of the other sciences, in spite of its complexity, is constant

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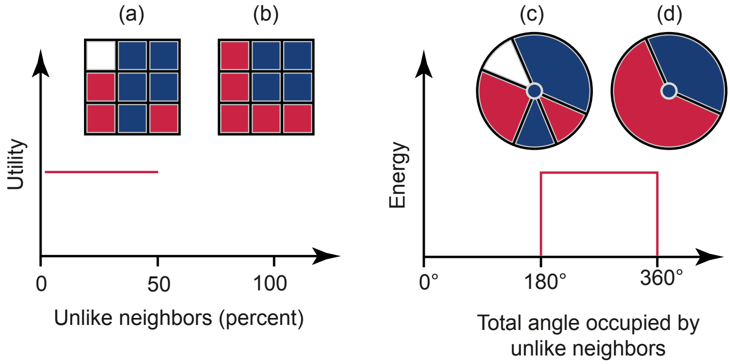

Figure 2.3 The transformation from the discrete Schelling model to a continuous model (Vinković and Kirman 2006); copyright National Academy of Sciences, U.S.A., used with permission.

and homogeneous."[4] Nevertheless, there exist models in physics that are at the heart of work on complex systems, and that could provide useful analogies for economists. Here we briefly examine one such model developed by Vinković and Kirman (2006).

The idea here is to think of people as particles with energy. A particle with high energy corresponds to an individual with low utility. To build the analogy, suppose that there is a continuum of individuals and locations, rather than the finite numbers in the Schelling model. Each individual can then be identified as a point in two-dimensional space. The neighborhood composition associated with each point is simply the total angle occupied by like and unlike neighbors, as shown in the right panel of Figure 2.3.

An individual's utility, or equivalently a particle's energy, depends on the size of the angles corresponding to unlike neighbors. Vinković and Kirman assume that the higher the proportion of unlike neighbors, the lower the utility (the higher the energy); thus, there is a monotonic preference for own-group neighbors. A physical system will "self-organize" so as to minimize its total energy. It is clear that the only individuals who have low utility (high energy) are those who are at border points, in contact with members of the other group. Thus, if the system manages to organize itself into clusters to minimize total energy, it will constantly try to reduce the length of the border, as illustrated in Figure 2.4.

As a result, the boundary between any two clusters will be flattened over time. The only thing that will prevent this is free space which can serve as a barrier between the two groups (Figure 2.4b). Examination of the parameters of this physical model reveal a number of interesting features. In particular,

[4] J. M. Keynes to Harrod, July 10, 1938, http://economia.unipv.it/harrod/edition/editionstuff/rfh.34a.htm (accessed Feb. 27, 2016).

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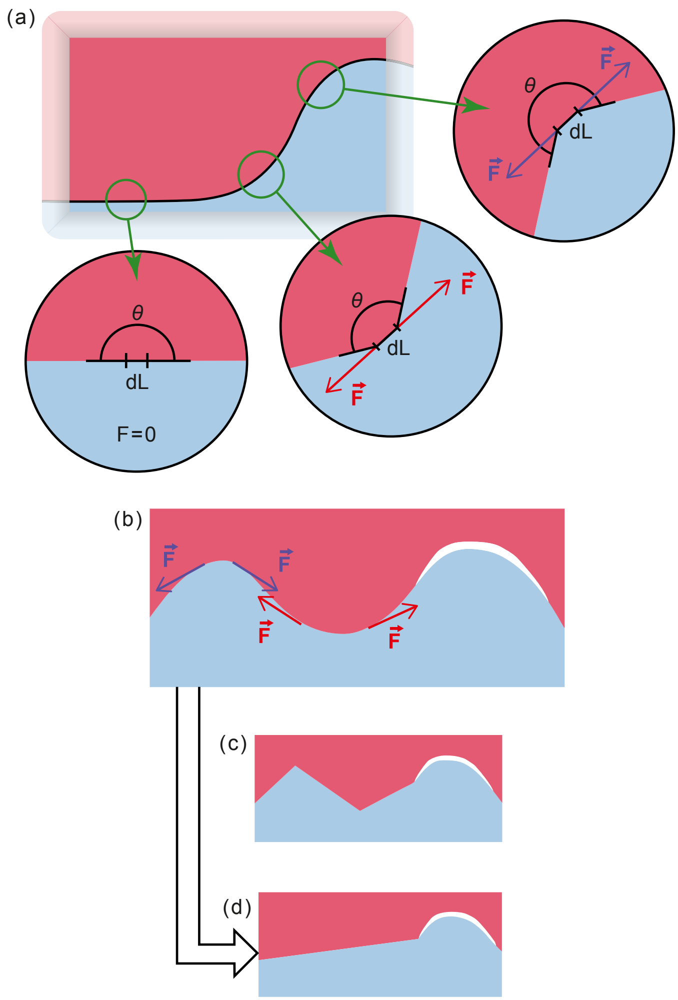

Figure 2.4 (a) Shows the way in which the surface of the cluster is flattened, (b) the surface does not flatten because of the open (white) space (Vinković and Kirman 2006); copyright National Academy of Sciences, U.S.A., used with permission.

an increase in the number of free spaces may lead to the system breaking up into small clusters, somewhat akin to the formation of a glass-like structure, which suggests that in relatively sparsely populated regions, small independent segregated clusters of individuals may emerge. In addition, if one has too few spaces, segregation does not develop and the system contains many individuals who are frustrated but unable to move. Thus, if one were interested in trying to prevent segregation, one would like to have a situation in which very few property locations are vacant. Note, however, that in this model reduced segregation comes at the cost of lower homeowner utility.

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The model can be extended by introducing preferences over the affluence of one's neighbors, as well as a housing market. The natural idea is that people will have higher utility if they can get the same housing cheaper, holding constant neighborhood characteristics. There is some discussion in the literature as to whether individuals prefer to live in areas where the average income is higher than their own or the opposite. The intuition for the first hypothesis is that wealthier individuals will pay for better services and infrastructure, directly or through taxes (Wilson 1987; Jencks and Mayer 1990; Durlauf 1996). However, some authors (Davis 1966; Jencks and Mayer 1990) suggest that children who are less privileged in an affluent area suffer as a result (e.g., they lose out in competition at school). If one accepts the hypothesis that people prefer to live with wealthier neighbors, then the physical analogy can be extended to show that rich clusters will form within segregated areas (Vinković and Kirman 2006).

Although this model is highly abstract, and neglects a number of important ingredients, it does illustrate that alternatives to the standard equilibrium approach can yield useful insights. The simple physical analogy permits us to understand the formation of total segregation in large clusters when population density is high, the formation of smaller groups in less populated areas, and of separate affluent clusters within segregated areas.

Equilibrium Approaches

None of the above arguments are meant to suggest that alternatives to equilibrium reasoning are superior to standard models in all cases, only that a diversity of methods can result in deeper understanding. Even in the analysis of segregation and homophily, equilibrium models have proved useful, but equilibrium predictions often need to be refined using disequilibrium reasoning.

As an example, Sethi and Somanathan (2004) extend the Schelling model by allowing for income heterogeneity within and between groups and continuous preferences over the mean income and racial composition of neighborhoods. In this case, individuals can sort on multiple dimensions—race and income—and equilibrium patterns can be highly segregated on one dimension while being quite integrated on the other. However, there is typically a multiplicity of equilibria in this model, and these differ quite fundamentally in their qualitative properties. The authors therefore appeal to a notion of stability based on disequilibrium dynamics.

Invoking this refinement narrows the set of equilibria, and Sethi and Somanathan show that at stable states, those who belong to a group that is poorer on average end up in neighborhoods where the mean income is itself lower. That is, conditional on one's own income, the income of one's neighbors is lower if one belongs to a lower income group. Yet there exist equilibria (unstable under the specified dynamics) at which the opposite is true. The

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equilibrium concept alone cannot distinguish between these types of equilibria; intuitively plausible but necessarily *ad hoc* dynamic arguments are required.

A very different example comes from Currarini et al. (2009), who construct an equilibrium model based on search intensity that accounts for both homophily and a *friendship gradient*—the tendency of those belonging to a majority group in their microenvironment (such as a school) to have a larger number of friendships. The key idea is that the search for friends is costly, and the outcome of search depends on the relative intensity of search by own-group and out-group members. If groups are of unequal size and search intensity is identical across groups, then individuals will be more likely to encounter members of larger groups. If own-group friendships are valued more than out-group friendships, then members of small groups will lower search intensity relative to members of larger groups. This further increases the likelihood that a random encounter will be with a majority group member, since they are both more numerous and are searching with greater intensity. The latter effect results in a larger number of friendships for those in the majority.[5]

As in Sethi and Somanathan (2004), however, equilibria with counterintuitive and counterfactual properties can exist. For instance, there can be an equilibrium in which the minority group exerts greater search effort, based on expectations that a random encounter will result in a match with a fellow minority group member. These expectations are fulfilled in equilibrium, precisely because they give rise to greater minority search effort. In such an equilibrium, however, the friendship gradient is inverted: majority group members have fewer friends on average. Ruling out such equilibria again requires some appeal to arguments that deviate in some way from equilibrium reasoning.

Preference Evolution

So far we have taken preferences over the composition of neighborhoods or networks to be exogenously given. These preferences can be endogenized using evolutionary arguments.

There are a number of reasons why interaction with others who share a culture or identity may be beneficial. There are also circumstances in which payoffs may be higher when interactions involve individuals from different groups. In the terminology of Fu et al. (2012), the former may be viewed as gains from *synergy* whereas the latter can be seen as gains from *specialization*.

Gains from synergy can arise under conditions of incomplete information, when the interpretation of signals is important. This idea underlies a branch of the literature on statistical discrimination in economics, dating back to Phelps (1972) and developed further by Cornell and Welch (1996) and Lundberg and

[5] Random encounters in this model result in heterophily for members of small groups, so Currarini et al. (2009) introduce a bias in the matching process to account for high levels of homophily among all groups.

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Startz (2007). To illustrate, consider an employer who is faced with a large pool of applicants drawn from different identity groups. There is heterogeneity in productivity or talent across individuals within groups, but each group has the same distribution of productivity. Suppose further that the employer cannot directly observe the productivity of individual applicants, but must make an inference based on an idiosyncratic and partially informative signal, such as a test score or interview performance. If signals are easier to interpret when both sender and receiver belong to the same group, then the employer will hire a within-group applicant with high likelihood.

To see why, note first that among those with negative signals (suggesting low productivity), out-group members will be preferred to in-group members. This is because the latter will be more reliably of low productivity. By the same token, among those with strong positive signals, in-group members will be preferred. So the most attractive and least attractive applicants will all be in-group, whereas out-group applicants will occupy an intermediate space. When the pool is large, choosing the applicant with the highest expected productivity will result in workplace homophily. This is despite the fact that the groups (by assumption) do not differ in the aggregate distributions of productivity levels.[6]

Although the statistical discrimination literature is based on optimal behavior and Bayesian reasoning, without any intrinsic preference for within-group interactions, it identifies a channel through which a preference for homophily may be adaptive. However, excessive homophily may also be maladaptive if there are benefits to diversity in teams. The effectiveness of a team depends not only on some simple aggregate of individual talents, but also on the *distribution* of characteristics in the team. A diversity of perspectives can, in principle, enhance or disrupt overall performance depending on the nature of the task at hand.[7]

Both synergy and specialization are considered by Fu et al. (2012), who examine conditions for the evolution of a preference for homophily in a population composed of distinct phenotypic groups. Each individual, i, is endowed with a preference parameter, $p_i \in [0,1]$, where higher values of p_i indicate a greater preference for homophily. Individuals are matched uniformly at random and interact with a probability that depends on their preferences and phenotypes. Specifically, if two individuals, i and j, are matched, they interact with probability $p_i p_j$, if they belong to the same group, and probability $(1 - p_i)(1 - p_j)$ otherwise.

Payoffs from within-group interactions are given by a, and those from across-group interactions by b. The relative values of these payoffs depend on

6 For a related argument based on the greater predictability of in-group members in environments requiring coordination, see Kets and Sandroni (2014).

7 See Hong and Page (2004) for a formalization of the idea that the benefits of diversity arise from the absence of replication in teams faced with complex tasks. In addition, it appears that the effectiveness of a diverse group depends on interpersonal congruence, or "the degree to which group members see others in the group as others see themselves" (Polzer et al. 2002:298).

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the advantages of within-group synergy as compared to across-group specialization. A key finding is that the equilibrium distribution of preferences may favor homophily even if b substantially exceeds a. This can occur, for instance, if one group is much larger than the other, so that those with heterophilic preferences have difficulty finding acceptable matches. In this case homophily is favored even in the smaller group: those with heterophilic preferences are rejected by the larger group and reject those in their own group, thus finding it impossible to interact.

One weakness of this model is that individuals with homophily parameter $p = 1/2$, who are equally happy to interact with members of either group, can suffer a significant disadvantage when most individuals in the population have a preference for homophily ($p = 1$). Conditional on being matched with their own type, their interaction probability is just one-half, while those with strong preferences for homophily interact with certainty when matched within group. This can prevent the entry of such "open-minded" types when a preference for homophily is widespread in all groups.

To correct for this, one can iterate the matching structure in Fu et al. (2012), allowing those unmatched in an initial round to try and find compatible matches with others who remain unmatched. Repeating the process until no two individuals with compatible preferences remain unmatched, one may then compute payoffs and examine evolutionary stability. Under these conditions, it is clear that as long as the payoff from specialization exceeds that from synergy, a population with complete homophily cannot be stable. In such populations, the entry of a small number of individuals with tolerant preferences would be destabilizing since the entrants would obtain strictly higher payoffs when they match with each other across groups.

Interestingly, a population of fully tolerant individuals would not be stable either, since the entry of a small number of individuals with preferences for *heterophily* would be destabilizing. The entrants would always interact with those in other groups, while the incumbents would interact with all potential partners without distinction. Given that specialization payoffs exceed those from synergy, the entrants would proliferate under evolutionary pressure. In fact, no monomorphic state can be stable: if all incumbents had preferences for heterophily, then some in the majority group would remain unmatched. As a result, the only stable states under evolutionary dynamics must involve population heterogeneity in preferences. A full characterization of such states remains an open topic for research.

For a concrete example of changes in both the degree of homophily and the preferences which underlie it, consider the composition of university faculty in South Africa (Cowan et al. 2015). The racial and gender composition of academics in the science system differs substantially from the composition of the population at large. Typical explanations rely on socioeconomic disparities and political considerations that are largely exogenous to the science system itself. Cowan et al. explore the manner in which the entry of black and female

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scientists into the higher education system is affected by the existing composition within the system. In particular, the relatively strong tendency toward homophily that is observed in supervisor-student relationships tends to maintain the status quo. The empirical evidence makes it difficult to judge whether the observed level of homophily actually slows down or even impedes convergence toward the natural, population-level composition. Their theoretical model shows that homophily needs to be extremely strong to sustain a certain imbalance in composition over a longer period of time. Even with very low levels of homophily, however, deviations from the population-level composition should be expected. Furthermore, if one allows for a change in the preference for homophily of those who recruit a student from a different background, the evolution to a more representative distribution is accelerated. Nevertheless, even if positive discrimination in favor of black hiring were to be strongly implemented, the model suggests that the passage to a racially representative academic population would take more than a century. The avenue to a reasonably representative academic population seems to be a significant expansion of the university system.

Other Applications

We have used the example of homophily to illustrate the potential value of models based on evolutionary arguments and a complex systems perspective. Many other potential applications are possible using this approach.

Consider, for instance, the case of trading in financial markets. The valuation of securities such as stocks and long-term bonds relies on beliefs about the profitability of companies stretching far into the future. Information about these prospects can be immensely valuable to those who are early in acquiring it, and enormous amounts of effort and expense are devoted to discovering information that has not yet been incorporated into asset prices. However, trading on information has an impact on prices and volume, and this provides opportunities for some speculators to extract information from market data without incurring the substantial costs of acquiring it directly (Grossman and Stiglitz 1980).

The speed with which this latter activity now occurs is staggering, given the algorithmic implementation of high-frequency trading strategies.[8] The distinction between fundamental strategies involving research about company prospects and technical strategies based on analysis of market data has been relevant, though, for as long as markets for securities have existed. In an early analysis of the interaction between such strategies, Beja and Goldman (1980) argued that markets dominated by fundamental strategies would have low

8 For discussion of high-frequency trading in the context of a rich market ecology, and the role played by such strategies in the "flash crash" of May 2010, see, e.g., Kirilenko et al. (2011).

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volatility, whereas those dominated by technical analysts would be subject to bubbles and crashes.

While market dynamics depends on the composition of trading strategies, this composition itself evolves under pressure of differential profitability. In stable markets where prices reliably track fundamentals, technical analysis can be especially profitable since information can be extracted from market data at a fraction of the cost incurred by fundamental analysts. If technical strategies proliferate as a result, the market is eventually destabilized. An asset price bubble can further damage returns to fundamental strategies, as asset mispricing becomes increasingly severe. The inevitable crash that results restores the profitability of fundamental research, setting the stage for a period of low volatility (Sethi 1996). This "endogenous regime switching" between stable and unstable markets is consistent with the robust empirical finding that volatility in asset markets tend to be clustered.

Brock and Hommes (1997) provide another illustration of this phenomenon: when markets are volatile, individuals have an incentive to forecast based on information that is costly to obtain and in this case, the system will settle down to follow the fundamentals. Once this happens, however, the system becomes easier to forecast and individuals revert to a forecasting rule that is much less costly. The problem is, once people all settle on such a strategy, the market is destabilized and individuals then go back to the old and more costly rule. Again, we see an interspersion of volatile periods with relatively calm episodes.

Our last example was developed by Föllmer et al. (2005). Here, individuals choose a forecasting rule that has exhibited the best performance up to the present time. Such rules can be self-reinforcing: the system exhibits positive feedback or "reflexivity," to use George Soros's term. Assume that there are technical traders or chartists who extrapolate from previous prices, and fundamentalists who believe that the price of the asset will come back to some fundamental value. When the chartists dominate the market they generate bubbles, but when (as inevitably happens) fundamentalists become dominant again, the market converges to an equilibrium price. The movement between the two extremes is derived using a model based on the herding behavior of ants (Kirman 1993). Once again, the approach is very different from that of standard financial models. It does, however, provide an alternative notion of equilibrium, one in which there is a limit distribution of the prices of the asset. Yet, to be fully consistent with an evolutionary approach, one would need the fundamentals or the perception of the fundamentals to evolve over time.

This kind of evolutionary reasoning can also be used to examine strategies outside the financial sector, such as the degree to which nonfinancial firms choose short-term debt financing over long-term debt or equity. Under normal market conditions, short-term debt provides a cheaper source of funds for firms than long-term debt (the yield curve is upward sloping). The use of short-term debt to finance durable assets is, however, risky, because the debt needs to be

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periodically rolled over for the life of the financed assets. As long as market conditions remain tranquil, and debt rollover remains unproblematic, the pressure of differential profitability will lead to an increased reliance on short-term debt. This increased need for periodic refinancing itself makes a market disruption more likely. When such a disruption does eventually occur, firms with limited reliance on short-term debt are more likely to survive. The resulting shift in the composition of financing strategies restores stability and sets the stage for a new expansion. This fluctuation over time in the distribution of financial practices and the stability of debt markets was a central theme in the work of Hyman Minsky (1975, 1982, 1986).

As in the case of homophily, equilibrium models have generated many useful insights in finance, especially when some departures from optimality on the part of some subset of market participants is allowed. Kyle (1985) as well as Glosten and Milgrom (1985) have developed influential theories of market-maker pricing when some traders have superior information while others have urgent liquidity needs. Even bubbles and crashes can be shown to arise in equilibrium models, provided that some departures from optimality on the part of a small subset of market participants are permitted (Abreu and Brunnermeier 2003). There is no doubt that the equilibrium method imposes discipline on economic modeling, and avoids the tailoring of behavioral assumptions to the problem at hand. But it also makes restrictive assumptions about knowledge and sophistication. The development of models based on evolutionary reasoning and a disequilibrium perspective can provide a useful complement to these more orthodox exercises. This is especially the case when large numbers of interacting agents with severely limited knowledge of each other's motives and beliefs are involved.

Our goal here has been to illustrate, using a few selected examples, the value of methodological pluralism and to stress the need for openness to an evolutionary and complex systems perspective. While social networks, endogenous preferences, and trading strategies are natural areas of application, they are by no means exhaustive. We believe that this alternative perspective has the potential to enrich our understanding of a very broad range of economic phenomena.

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